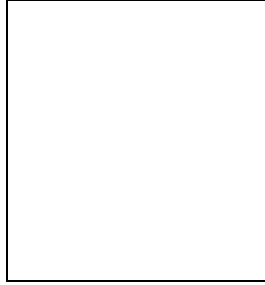


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**INCLUSIVE DIFFRACTIVE DIS AT HERA**

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Recent precision measurements of diffractive neutral current deep inelastic  $ep$  scattering are performed by the H1 and ZEUS Collaborations at the HERA collider in a wide range of photon virtuality  $Q^2$ . The first measurements of the large rapidity gap cross sections in charged current processes at high  $Q^2$  are also presented. The results are compared with model predictions based on parton density functions obtained from a DGLAP QCD fit to the data.

## 1 Introduction

Diffractive processes in deep-inelastic  $ep$  scattering (DIS) at HERA are characterized by the presence of a large rapidity gap (LRG) between the leading proton (or the proton dissociation system  $Y$ ) and the rest of the hadronic final state  $X$  (Fig. 1). Here the variables  $W$ ,  $M_X$  and  $M_Y$  denote the CMS energy of the virtual photon and the proton and the effective masses of the systems  $X$  and  $Y$ , respectively. Within Regge phenomenology, diffractive processes are described by the exchange of the Pomeron trajectory. As a result the Pomeron intercept can be extracted through a Regge fit to the data. The presence of a hard scale - the photon virtuality  $Q^2$  - enables perturbative QCD to be applied to the data. Within the QCD framework the diffractive events can be interpreted as processes in which a colour singlet combination of partons is exchanged.

The structure of the colour singlet can be studied using a QCD approach based on the hard scattering factorization theorem and parton density functions (PDFs)<sup>1</sup>. In the charged current

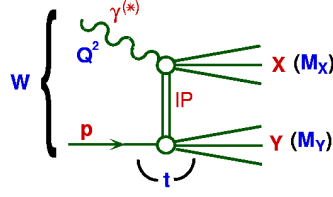


Figure 1: The diffractive process  $\gamma^* p \rightarrow XY$  at HERA.

processes the structure of the color singlet could be probed by its coupling to the W boson.

The diffractive reduced cross section is defined by

$$\frac{d^4\sigma^{ep \rightarrow eXp}}{dx_{\mathbb{P}} dt d\beta dQ^2} = \frac{4\pi\alpha^2}{\beta Q^4} \left(1 - y + \frac{y^2}{2}\right) \cdot \sigma_r^{D(4)}(x_{\mathbb{P}}, t, \beta, Q^2), \quad (1)$$

where  $y$  is the inelasticity,  $t$  is the 4-momentum transfer squared at the proton vertex,  $x_{\mathbb{P}}$  is the longitudinal momentum fraction of the incident proton carried by the colour singlet ( $\mathbb{P}$ ) and  $\beta = x/x_{\mathbb{P}}$  is the longitudinal momentum fraction of the colour singlet carried by the struck quark. The  $\beta$  variable for diffractive DIS processes is analogous to the Bjorken scaling variable  $x$  for inclusive DIS.

$\sigma_r^D$  is related to the diffractive structure functions  $F_2^D$  and  $F_L^D$  by:

$$\sigma_r^D = F_2^D - \frac{y^2}{1 + (1 - y)^2} F_L^D. \quad (2)$$

Thus  $\sigma_r^D \simeq F_2^D$  is a good approximation except at the highest  $y$ . The measurements are integrated over  $|t| < 1 \text{ GeV}^2$  because the leading proton is not detected:  $\sigma_r^{D(3)} = \int \sigma_r^{D(4)} dt$ .

## 2 Factorization properties of diffractive DIS

The validity of the QCD hard scattering factorization for diffractive DIS was proven by Collins<sup>1</sup>. It states that at fixed  $x_{\mathbb{P}}$  and  $t$  the diffractive cross section is a product of diffractive proton parton density functions  $f_i^D$  and partonic hard scattering cross sections  $\sigma^{\gamma^*i}$ :

$$\sigma_r^{D(4)} \sim \sum \sigma^{\gamma^*i}(x, Q^2) \otimes f_i^D(x, Q^2, x_{\mathbb{P}}, t). \quad (3)$$

$f_i^D$  are universal for diffractive  $ep$  DIS processes (inclusive, dijet and charm production) and obey the DGLAP evolution equations.  $\sigma^{\gamma^*i}$  are the same as for inclusive DIS. This approach allows us to test the diffractive exchange within the perturbative QCD framework and extract diffractive parton density functions. A NLO DGLAP QCD fit can be applied to diffractive DIS in analogy with inclusive DIS.

An additional assumption is made in the present analysis, that is, that the  $x_{\mathbb{P}}$  and  $t$  dependences of diffractive parton densities factorise from the  $\beta = x/x_{\mathbb{P}}$  and  $Q^2$  dependences (Regge factorisation)<sup>2</sup>:

$$f_i^D(x_{\mathbb{P}}, t, x, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}}, t) \cdot f_i^{\mathbb{P}}(\beta, Q^2). \quad (4)$$

Here  $f_{\mathbb{P}}$  is the Pomeron flux factor and  $f_i^{\mathbb{P}}$  are Pomeron PDFs. Although there is no firm proof in QCD for this assumption it is approximately consistent with the present data. The  $x_{\mathbb{P}}$  dependence of the Pomeron flux factor was parameterized using a Regge motivated form:

$$f_P(x_P) = \int x_P^{1-2\alpha_P(t)} e^{B_P t} dt, \quad (5)$$

where  $\alpha_P(t) = \alpha_P(0) + \alpha'_P t$  is the Pomeron trajectory with the intercept  $\alpha_P(0)$ .

### 3 Diffractive DIS cross sections

#### 3.1 $W$ dependence of the diffractive cross section

ZEUS measured the  $W$  dependence of the diffractive cross section  $d\sigma/dM_X^2$ <sup>3</sup>. Using a new Forward Plug Calorimeter the acceptance was extended to higher  $M_X$  and lower  $W$  values in comparison with the previous measurement<sup>4</sup>. The results are presented in the kinematic range  $2.2 < Q^2 < 80 \text{ GeV}^2$ ,  $37 < W < 245 \text{ GeV}$ ,  $M_X < 35 \text{ GeV}$  and  $M_Y < 2.3 \text{ GeV}$ . The Pomeron intercept  $\alpha_P$  was extracted using a Regge motivated power-like fit  $d\sigma/dM_X^2 \sim (W^2)^{2\alpha_P(0)-2}$ . For  $M_X < 2 \text{ GeV}$  the diffractive cross section shows a weak  $W$  dependence and a strong decrease with  $Q^2$  consistent with a higher twist behaviour. For larger  $M_X$  values, a strong rise with  $W$  and a weaker dependence on  $Q^2$  are found. According to the optical theorem the total  $\gamma^*p$  cross section is also characterized by a power-like dependence on  $W$ :  $\sigma_{tot}^{\gamma^*p} \sim (W^2)^{\alpha_P^{tot}(0)-1}$ . The fit shows that the Pomeron intercept extracted from the diffractive cross section is smaller than that from the total  $\gamma^*p$  cross section (Fig. 2), but that the  $W$  dependences of the cross sections are similar:  $2\alpha_P - 2 \approx \alpha_P^{tot} - 1$ . The diffractive data are consistent with a "soft Pomeron"<sup>6</sup> at low  $Q^2$ , but also suggest the increase of the Pomeron intercept with  $Q^2$ , indicating possible Regge factorization breaking.

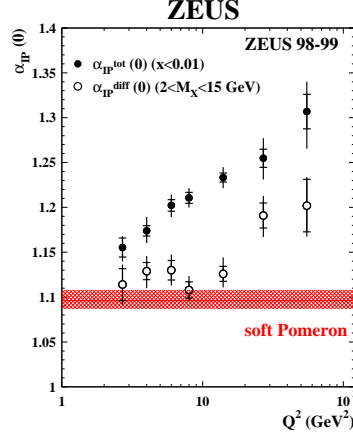


Figure 2: The Pomeron intercept as a function of  $Q^2$  obtained from the  $W$  dependence of the total  $\gamma^*p$  cross section and the diffractive cross section  $d\sigma/dM_X^2$ .

#### 3.2 Diffractive reduced cross sections at medium and high $Q^2$

Recent H1 and ZEUS measurements in which the leading proton is detected in proton spectrometers are described in<sup>7</sup>. The selection of diffractive events containing a large rapidity gap (LRG) yields better statistical precision. In these events the leading proton is not detected and the kinematics are reconstructed from the hadronic system  $X$ . Figure 3 shows a compilation of the H1 and ZEUS measurements based on the selection of either a leading proton or a large rapidity gap in the final state. Good agreement between the two methods and the experiments points to a small contribution from proton dissociation processes to the LRG data.

The H1 LRG data measured in the range of  $6.5 < Q^2 < 120 \text{ GeV}^2$ <sup>8</sup> were used to perform a NLO QCD fit<sup>9</sup>. In the fit the diffractive exchange is parameterized by light quark singlet and

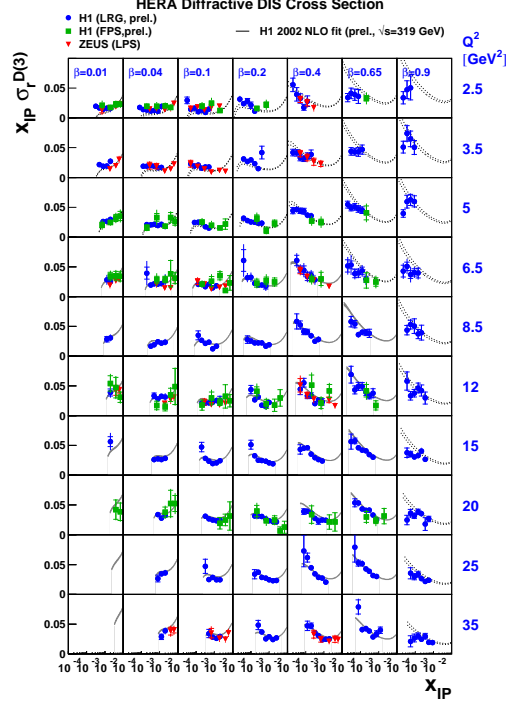


Figure 3: The diffractive reduced cross section measured in DIS processes with either a leading proton or a large rapidity gap in the final state.

gluon density functions at a starting scale  $Q_0^2 = 3\text{GeV}^2$  which are evolved according to the NLO DGLAP equations. The  $x_P$  dependence is assumed to factorise from the  $\beta$  and  $Q^2$  dependences and is described by a phenomenological Regge flux factor (5).

The momentum fraction carried by gluons is estimated to be  $75 \pm 15\%$ . This result is consistent with the result of the NLO QCD fit to the leading proton data performed recently by ZEUS<sup>5</sup>. PDFs extracted from the QCD fit to the diffractive cross sections can be used to test QCD factorization in the production of charm and dijets in  $ep$  DIS at HERA and  $p\bar{p}$  scattering at the TEVATRON<sup>10</sup>.

The H1 Collaboration has also measured the diffractive reduced cross section at high  $Q^2$ . The results are presented in Fig. 4. The QCD prediction based on the PDFs extracted from the H1 NLO QCD fit to the medium  $Q^2$  data<sup>8,9</sup> gives a good description of the high  $Q^2$  measurements, even though the NLO DGLAP evolution was performed over one order of magnitude in  $Q^2$ . The data show that the contribution of a sub-leading trajectory is needed at high  $x_P$  and low  $\beta$ .

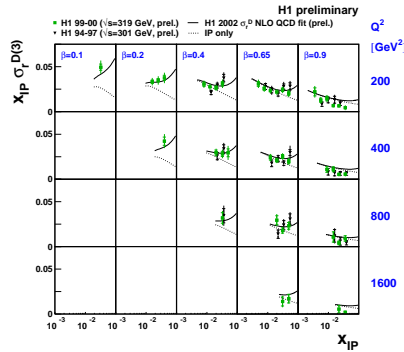


Figure 4: The diffractive reduced cross section as a function of  $x_P$  with the predictions based on the H1 NLO QCD fit.

## 4 Charged current cross sections

The charged current process  $ep \rightarrow \nu XY$  with a large rapidity gap in the final state has also been studied by H1 and ZEUS. In the diffractive CC process the W boson probes the partonic structure of the colour singlet exchange. The LRG CC events were selected in the kinematic range:  $Q^2 > 200\text{GeV}^2, y < 0.9, x_P < 0.05$ .

The LRG CC cross sections and their ratios to the inclusive CC cross section measured by H1 and ZEUS in the range  $Q^2 > 200\text{GeV}^2, y < 0.9, x < 0.05$  are:

ZEUS:  $0.49 \pm 0.20(\text{st}) \pm 0.13(\text{sys})$  pb

H1:  $0.42 \pm 0.13(\text{st}) \pm 0.09(\text{sys})$  pb

ZEUS:  $2.9 \pm 1.2(\text{st}) \pm 0.8(\text{sys})\%$

H1:  $2.5 \pm 0.8(\text{st}) \pm 0.6(\text{sys})\%$

The results from the two experiments are in good agreement.

The data were used to test predictions based on PDFs extracted from the diffractive NC DIS. A model based on PDFs extracted from the H1 LO QCD fit<sup>11</sup> gives reasonable description of the ZEUS LRG CC data after statistical subtraction of the non-diffractive background. The data are also consistent within the experimental errors with the non-diffractive distribution alone.

The H1 LRG CC cross sections are in good agreement with predictions of the recent H1 NLO QCD fit<sup>9</sup> assuming an additional contribution from a sub-leading reggeon trajectory.

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